4 A short description of the basics of closed loop control theory

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4.1 The control characteristics of secondary control in comparison to normal hydrostatics and valve controls

In conventional hydraulic closed loop control, the control element (the variable pump or valve) passes a constant flow to a fixed displacement motor, i.e. the set value corresponds approximately to speed.

In contrast to this, the control element of the secondary unit (of the swashplate) changes the displacement and therefore the torque of the unit, i.e. the control value corresponds closely to the acceleration which, in turn, is dependent upon the load torque.

The differences become clear if the control values for the various types of closed loop control are compared for the operation of a speed profile *(see diagram 5)*.

As can be seen, the swivel angle of the secondary unit is almost independent of speed. In an open loop control, without feedback, (with input at the swivel angle by hand) this is totally impossible!.

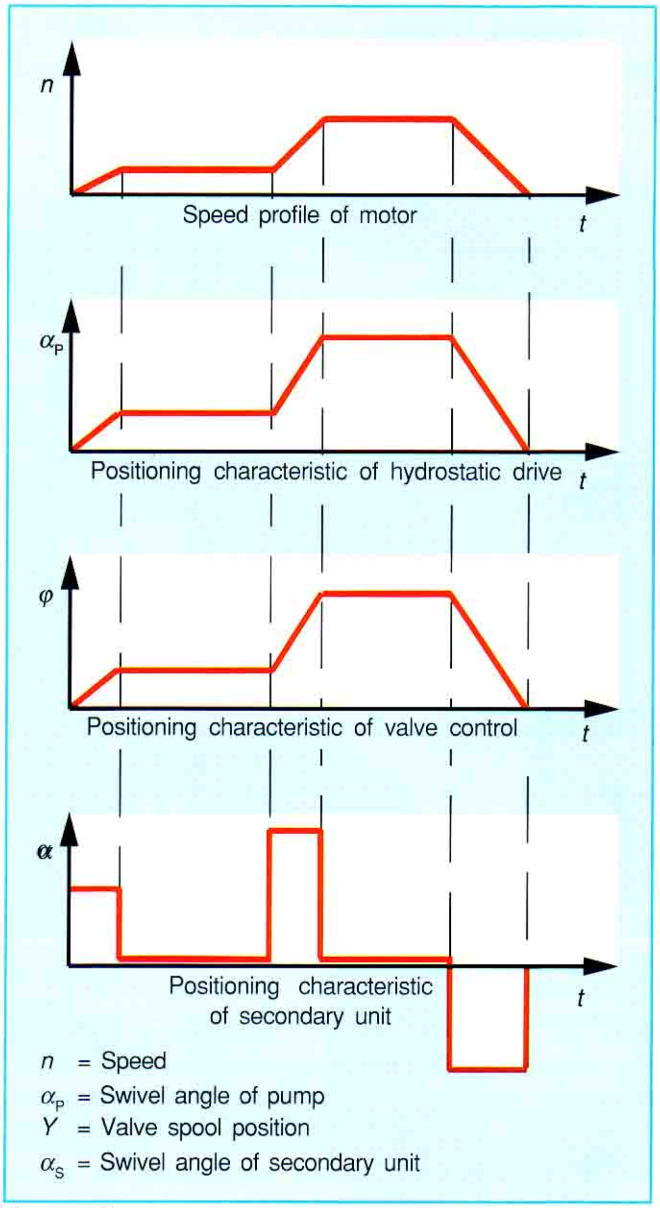

Diagram 5

4.2 The characteristics of the positioning system.

Construction

The positioning cylinder which adjusts the angle of the swashplate is controlled by a valve *(see Fig. 20, page 20)*. The cylinder position corresponds to the torque. This construction therefore means that the system has an integrating time delayed characteristic (I-T_4), *see Fig. 11*.

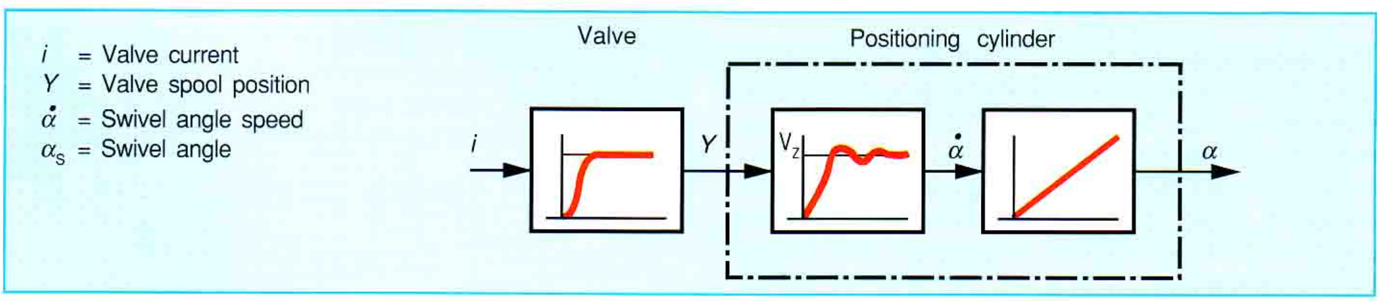

Figure 11: *Block circuit diagram for swivel angle setting*

This integral characteristic has a negative influence on the stability of the secondary unit in a speed control or positional control loop. By feeding back the swivel angle value in order to generate a closed loop positional control for the swivel angle, the integral characteristic is converted into a proportional - time delayed characteristic (P-T_5) *(see Fig. 12).*

Thus, due to the closed loop control of the swivel angle position, a better control characteristic is achieved for the secondary unit as the position of the swivel angle can be held exactly.

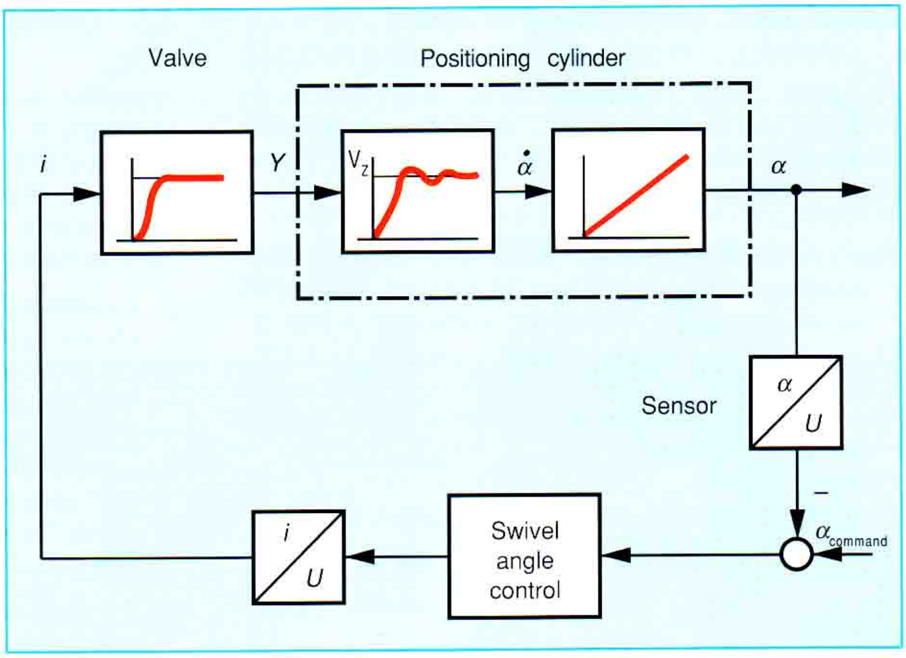

Figure 12: *Block circuit diagram for swivel angle setting control loop*

4.3 A description of the speed characteristics

Referred to swivel angle, the speed has a proportional time delay characteristic (P-T_1), *(see Fig. 13).*

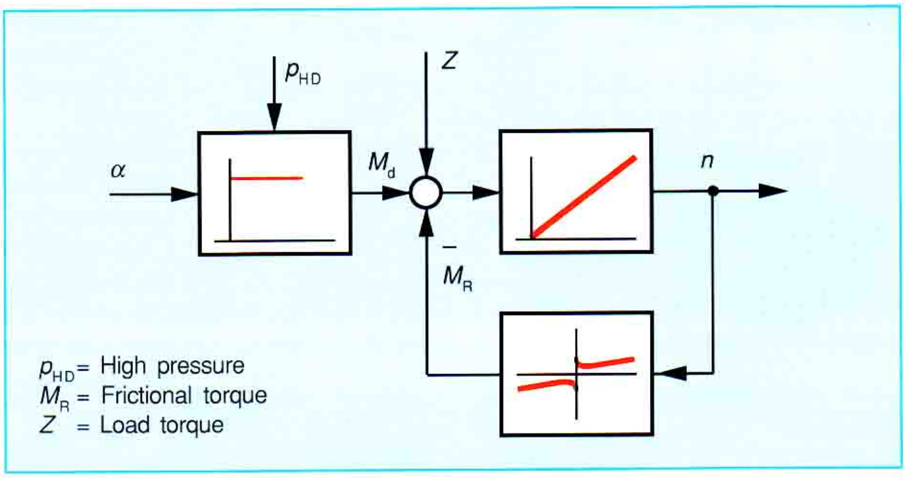

Figure 13: *Block circuit diagram of the speed relationships*

As can be seen from *Diagram 6,* a change in swivel angle causes the speed to change from zero to maximum (Z = 0).

As the secondary unit is only operated in the lower end of the achievable speed range in which the friction is only a percentage of the maximum torque, the system has almost an integral characteristic. Thus for a constant speed under stable conditions, relatively small changes in the disturbance torque Z lead to an acceleration or deceleration occurring. At a constant swivel angle, this causes relatively large speed variations, even to the extent of stopping the unit or to over speed - a recurring condition causing oscillation. The swivel angle must therefore be continually corrected in order to achieve a constant speed.

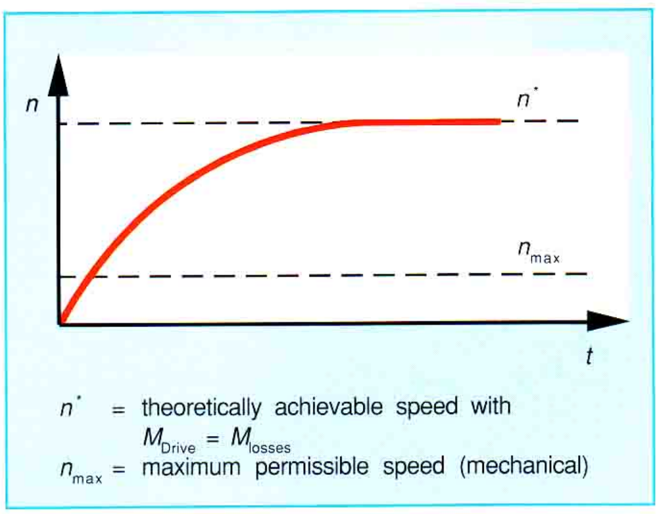

Diagram 6: *Stepped response in speed*

4.4 Closed loop control of speed

An important area of application for secondary controls is in closed loop speed controls. In these, the actual value for speed is determined by either a tacho-generator or a rotary pulse generator.

The control difference is fed via a suitable regulator and a subsidiary angle control loop to form the command value for the system. The swivel angle control loop is basically a valve controlled cylinder drive *(Fig. 11 & 12).*

The structure of the block circuit diagram for this control is shown in *Fig. 14.*

Due to the influence of friction and load torque, a specific swivel angle other than zero is required for a constant speed.

When applying a speed control loop with proportional characteristics, an error in speed control occurs which is dependent upon the opposing torques and upon the gain of the control amplifier.

This control variation can be compensated for by utilising a proportional - integral transfer function (PI regulator) within the speed control loop.

4.5 Closed loop control of position

In position control, the rotary angle traveled is measured by means of a rotary pulse generator and counter and compared in a digital computer to the preset rotary angle command. From this, the rotary angle difference (the following error) is generated. There are two ways in which this can be achieved:

a) A commercially available control may be used which either contains a P regulator for position control which can be amplified in order to produce the control value from the rotary angle difference, or which gives a speed command output dependent upon distance. For this, a subsidiary speed control loop is required such as is shown in *Fig. 14.* The overall control loop is then as is shown in the block circuit diagram in *Fig. 15.*

b) An "in house" control can be used with a powerful and specially designed control algorithm to suit the secondary control. This means that the subsidiary analogue control loop can be omitted and the digital computer then generates a direct command value for the analogue swivel angle control. The block circuit diagram is then as is shown in *Fig. 16.*

Utilising the almost integral characteristic for speed with its real integral characteristic for swivel angle *(as described in section 3.3)* a quasi double integral characteristic is achieved in the positional control loop. For this, and for the position control loop, a speed feedback is required. This can be achieved either by a subsidiary speed control loop *(example a)* or by means of special algorithm in a digital position control *(example b).*

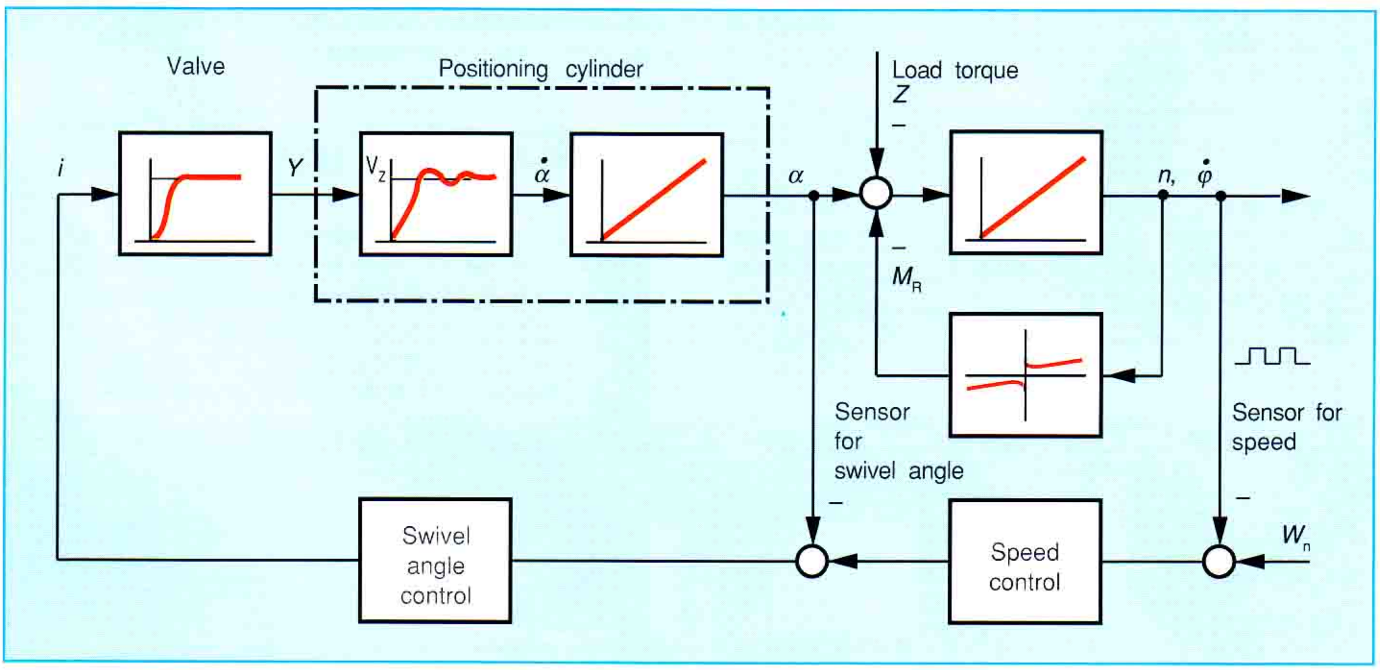

Figure 14: *Block circuit diagram for the speed control loop of a secondary unit*

As in the case of speed control the influences of friction and load torque produce a residual control variation.

However, a PI positional control would lead to oscillation occurring due to the integral characteristic of the swivel angle and is therefore unsuitable. The remaining control variation can however, be compensated for by means of a special algorithm matched to the requirements of secondary control.

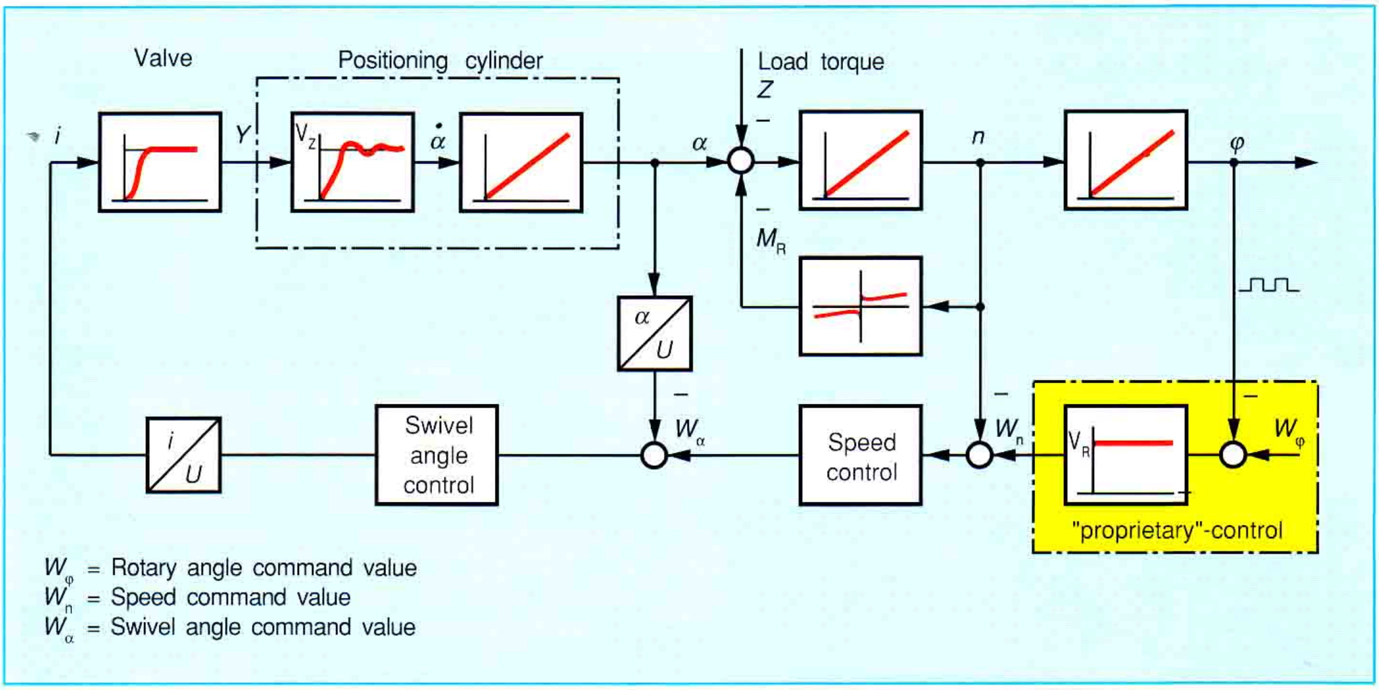

Figure 15: *Position control loop with "proprietary" control in a cascade structure for closed loop control of speed and swivel angle*

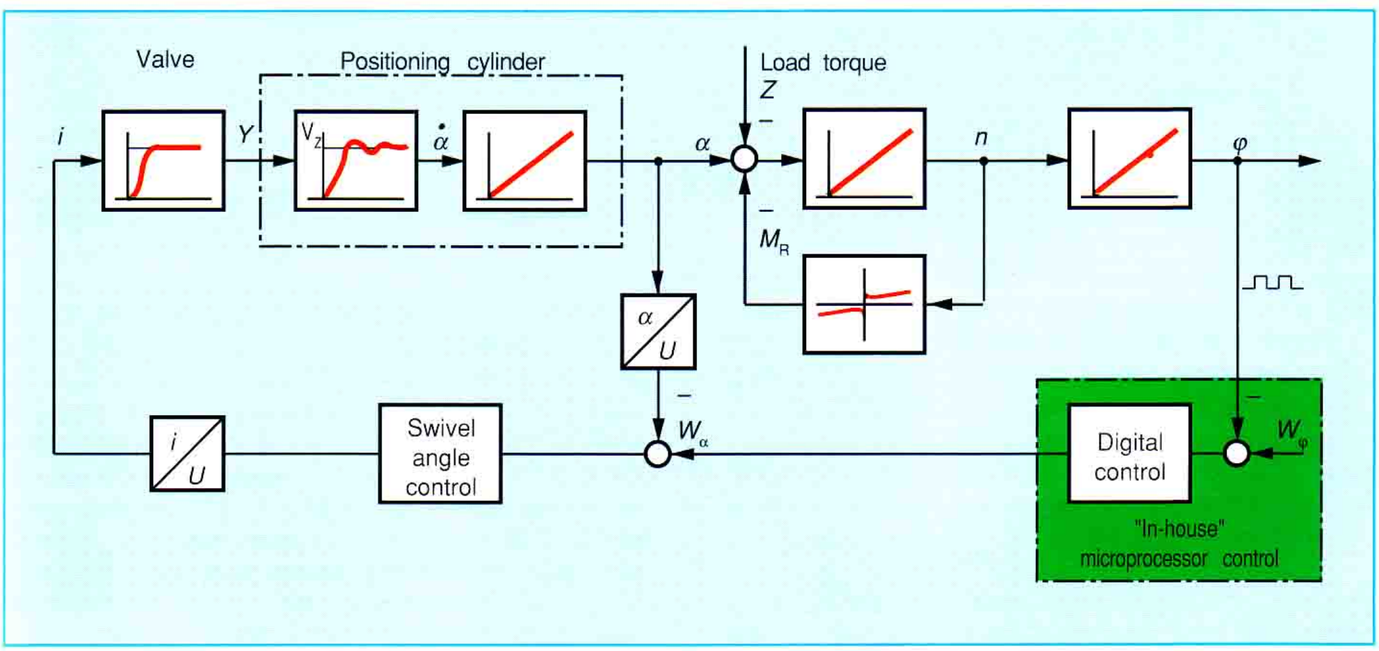

Figure 16: *Position control loop with "in-house" microprocessor control*